
OPEN
GUIDED
STRUCTURED
CONFIRMATORY

Open-Ended Inquiry

Practical ways of implementing inquiry in the chemistry classroom.

Lindsay Wheeler and Randy Bell

"Oh, I don't know if I can do inquiry in my classroom. It's too hard, and I don't even know where to begin."

How often have you heard comments like those? Maybe you've made them yourself. Inquiry has a reputation for being a great way for students to learn but difficult for teachers to implement. It doesn't have to be that way. Inquiry comes in many forms, which can be adapted for any science classroom at any point in the year for any level of student. In this article, we describe how to help chemistry students develop a method to answer their own research question, called *open* inquiry, using the reaction of hydrochloric acid and aluminum foil as an example. Open inquiry isn't the only option. We explain how to structure this activity to accommodate students' varied experience and comfort levels with inquiry. Teachers can also use this straightforward method to modify other activities they're already using.

What is inquiry, and why is it important?

A practical definition of inquiry is "an active learning process in which students answer research questions through data analysis" (Bell, Smetana, and Binns 2005, p 31). Inquiry incorporates the scientific practices of hypothesizing, investigating, observing, explaining, and evaluating (NRC 2011). Please note, however, three caveats:

1. Not all hands-on activities are inquiry, and not all inquiry is hands-on. Hands-on activities can be defined as any activity where students are interacting with or manipulating materials (Lumpe and Oliver 1991). For example, making 3-D molecules is hands-on but isn't necessarily inquiry. On the other hand, as long as students are analyzing data to answer a research question in their inquiry, they might get the data from the internet instead of collecting it themselves in a laboratory.
2. While inquiry is an essential part of science instruction (NRC 2000), other activities are also valuable. An effective teacher might chose to teach students the details of dimensional analysis through direct instruction, for example. Furthermore, teaching lab safety through inquiry would not be responsible!
3. Third, many teachers believe *all* inquiry should be open-ended, but that is not the case nor should it be (Settlage 2007). Different levels of inquiry help scaffold the process to support students' success.

Levels of Inquiry

Inquiry can be scaffolded by moving through four levels: confirmation, structured, guided, and open (Bell, Smetana, and Binns 2005). In all levels, students analyze data to answer a research question; the levels of inquiry differ in how much information the teacher provides (Figure 1).

In a *confirmatory* inquiry activity the teacher provides a research question and procedure, and students are asked to confirm a previously taught relationship. In *structured* inquiry, the research question and procedure are also provided but students don't know the expected outcome. In *guided* inquiry, students are given the question and develop a procedure to solve the problem. In *open* inquiry, students come up with their own research question and procedure. Figure 1 offers chemistry-based examples of these levels of inquiry, which teachers can use with activities of their own.

Most inquiry activities found in textbooks are at the confirmatory and structured levels (Pizzini, Shepardson, and Abell 1991). These can be called "cookbook" labs because

FIGURE 1

Examples of different chemistry activities at different levels of inquiry.

Inquiry Level	What Teacher Provides	Examples in Chemistry with Suggestions for Data Analysis	National Standards Addressed (Content Standard C)
1-confirmatory	Question, method, solution	*Example:* After learning about reaction rates, students confirm the relationship between temperature and rate using a reaction rate lab. *Data Analysis:* Reaction times can be graphed based upon increasing temperature.	Chemical Reactions, #4
2-structured	Question, method	*Example:* Students are given a procedure to determine the relationship between freezing point and the addition of solutes to solvent before learning about colligative properties. *Data Analysis:* Freezing point of a pure solvent can be compared to freezing point of solutions of varying concentrations.	Structure and Properties of Matter, #2
3-guided	Question	*Example:* Students develop a method of testing the reactivity of different metals in different salt solutions. *Data Analysis:* Qualitative evidence of a reaction for each metal in each solution can help develop the activity series.	Chemical Reactions, #3
4-open		*Example:* Using an online simulation, students develop a research question and procedure to understand the relationship between two of the variables: pressure, volume, and temperature. *Data Analysis:* Quantitative data from the program of the independent variable can be plotted against the dependent variable.	Conservation of Energy and the Increase in Disorder, #3

they typically provide step-by-step procedures. Not all cookbook labs are inquiry, but as long as students are analyzing data to answer a research question and supporting their results with evidence, they are performing inquiry. We recommend that students get experience with confirmatory and structured inquiry activities before moving on to guided or open inquiry.

Open inquiry: Reactivity of metals

Open inquiry is the most challenging to implement (Davis, Petish, and Smithey 2006). It can also be the most rewarding. This activity suggests techniques and resources to support it.

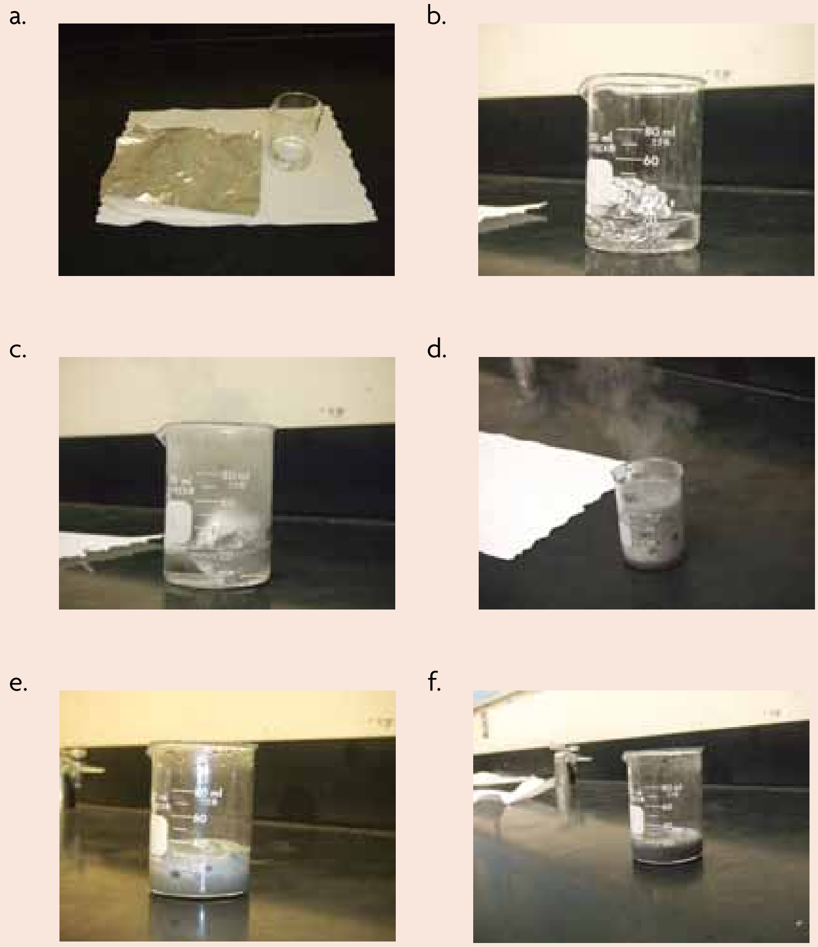
The demonstration

Used to teach reaction rates in chemistry, the activity starts with a demonstration in which students predict and observe what happens when the teacher places an aluminum foil ball in hydrochloric acid (Figure 2). (**Safety Note:** The teacher should wear safety goggles and gloves and, since hydrogen gas evolves, students should also wear safety goggles and stand back. The demonstration should be performed in a well-ventilated room or, when possible, under a fume hood.) This reaction takes one to three minutes to begin, depending on the concentration of the acid (~3M works well for the teacher's demonstration). Students get two benefits from observing the demonstration:

- They witness the general reaction, giving them a starting point for developing their own experiment, and
- They get excited about performing the experiment.

FIGURE 2

The progress of the reaction of 20 ml of 3M HCl with a ~0.5 g aluminum foil ball.



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Four-question strategy

We scaffold this open-inquiry activity using a modified version of the four-question strategy and an experimental design worksheet (Cothran, Geiss, and Rezba 2000). Used together, these two tools support students in identifying and designing their own viable inquiry investigation.

Discussing the four-question strategy (Figure 3) as a class helps students determine which variables to test. The four questions are

1. What materials are readily available?
2. How does the reaction act?
3. How can I change the materials to affect the action? and
4. How can I measure the response to the change?

When brainstorming answers to these questions, realize that students may come up with potentially impractical ideas for question 3. For example, they may want to try changing the concentration of acid, which can be too challenging if this lab is performed before discussing solutions. (If students really want to investigate concentration, you could have different premade solutions available for testing.) Question 4 is the most challenging for students. They may want to measure reaction time, for example. In this reaction, however, there

FIGURE 3

The four-question strategy for generating experimental ideas.

Questions	Possible Student Answers
Q1 What materials are readily available for conducting experiments on aluminum foil in acid?	Acid, aluminum foil, water, other metals, glassware, thermometers, hot plates, ice, stopwatches, ruler, balance
Q2 How does aluminum foil in acid act?	After time the aluminum foil bubbles and gas is formed, the beaker feels hot, the liquid changes color, and the foil disappears
Q3 How can I change the set of aluminum foil in acid materials to affect the action?	Mass of aluminum ball, number of Al balls, tightness of Al ball, volume of liquid, temperature of liquid, different metal
Q4 How can I measure or describe the response of aluminum foil in acid to the change?	Time from Al in liquid to no Al ball left, time from "smoking" until no Al ball left, max temperature, temperature change, color of liquid after reaction complete

Note: Underlined portions are left blank and filled in for the specific investigation. (Adapted from Cothran, Geiss, and Rezba 2000.)

are many points at which students could start and stop measuring time, and it is important to guide them to clear-cut possibilities. If students don't develop a standardized way to measure the response to change, they will struggle with the remainder of the experiment. Students may propose qualitative ways to measure the dependent variable such as how the solution changes color as the reaction progresses, which is acceptable.

Experimental design worksheet

Students use the experimental design worksheet (Figure 4) and their responses to the four questions (above) to determine what research question they will test. The four questions align with the experimental design worksheet, helping students develop an experiment with little assistance.

While the experimental design worksheet starts with the research question, students should first pick their independent and dependent variables (from questions 3 and 4, respectively). Students bring differing background experiences to the chemistry classroom; preferably, they should develop an experiment that's totally new to them. Watch out for students proposing multiple independent variables. Have them look to the experimental design worksheet, the four-question strategy sheet, and their peers or teacher for guidance. To help in this process, first break large classes into small groups.

After completing the experimental design, students write a procedure and data table, turning to the important practical aspects of the experiment (e.g., what volume of hydrochloric acid should they use? How do they determine if the aluminum foil balls are all the same size and mass?). The teacher should check the procedures and data tables to ensure lab safety before allowing students to proceed.

Experiment

Since hydrochloric acid is used during the experiment, students must follow all safety precautions, including using safety goggles and gloves. While the teacher's demonstration used 3M hydrochloric acid, for safety students should use 0.1M to 1M. The extra time needed for the reaction to start will allow students to record detailed observations. Students can perform two to three trials for each level of independent variable; if time is limited, they could do just one trial with a subsequent discussion about how this affects data reliability.

As the experiment proceeds, students record all data in their data table, and after completing the experiment, they work in their groups to analyze their data. For many teachers this is the most daunting part of an open inquiry activity because the results are not predictable. The data can vary, and a clear relationship between temperature and reaction rate may not be evident from every student's data. Use this opportunity to discuss that science is a human endeavor, and investigation results are often messy and complicated (Bell 2008).

Note: All liquid produced from this experiment should be collected, neutralized, filtered and disposed of in accordance with local policies (Arnett 1995).

FIGURE 4

Experimental design worksheet.

Research Question: How does the mass of the aluminum foil ball (Q3) affect the change in temperature of the hydrochloric acid (Q4) during the reaction?
Dependent Variable (selected from Q4): Change in temperature of hydrochloric acid. Initial temperature is measured before the aluminum foil ball is added, and final temperature is measured as the maximum temperature during the reaction.
Constants (all other Q3 options not selected as independent variable): Number of Al balls, tightness of Al ball, volume of liquid, initial temperature of liquid, metal used.
Hypothesis: The larger the mass of aluminum foil the larger the temperature difference of the hydrochloric acid.

IV (pick one from Q3): Masses of aluminum foil balls		
0.50 g Al foil	0.75 g Al foil	1.00 g Al foil
3 trials	3 trials	3 trials

(Adapted from Cothran, Geiss, and Rezba 2000.)

Communicating results

In addition to analyzing data, students must also communicate and explain their results. Each group should prepare a data table, graph, or other visual representation showing their results and any relationships derived from the data. This can be presented to the class as a poster or PowerPoint presentation or through individual lab reports (Figure 5, page XX offers a sample rubric). Students should work together to come up with scientific explanations based on their observations. They might explain, for example, the shorter reaction time needed for smaller masses of aluminum is due to there being fewer aluminum atoms to react. Students may have alternate explanations for certain phenomena, so it's essential to ensure they accurately understand what is occurring at the molecular level by addressing the inquiry activity continuously throughout the unit.

Figure 6 is a suggested schedule for this inquiry lab. This investigation can be used at any point during the year, incorporated into a unit on measurement, experimental design, reactions, or thermodynamics. Accordingly, students could be assessed on process skills such as data analysis or on specific content such as the relationship of surface area and reaction rate. Figure 6 also includes formative, authentic, and alternative assessments that align with different portions of the activity.

Modifications

SCILINKS
Keyword: Inquiry
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Enter code: TST091201

In the above investigation students develop their own question, methods, and solution in an open inquiry. But open inquiry is not always the most appropriate type (Settlage 2007). One way to modify this investigation is to provide students with the research question. This may be useful if there is limited time or to focus on specific content. For example, during a thermodynamics unit, students could investigate the relationship between surface area and reaction time. This can be done by changing the compactness of the aluminum foil ball or breaking one ball into multiple balls. Or, during a unit on reactions, students could investigate the relationship between types of metals and intensity of the reaction. By giving students a specific research question to answer, the experiment has become a guided inquiry.

Providing the students with not only the research question but also the procedure would make this a structured inquiry, which may be appropriate for students unaccustomed to developing experiments or to focus on having students analyze and draw conclusions from the data. Students could be provided a data table or asked to develop their own data table.

For both structured and confirmatory inquiry, students are given the question and procedure. Determine which type of inquiry is used in the activity by how you order the instruction. The inquiry is structured if it comes before the content is learned; it's confirmatory if the inquiry activity comes after (Bell, Smetana, and Binns 2005). For example, students could identify the relationship between surface area and reaction rate using different numbers of aluminum foil balls (structured), or they could first learn that increased surface area increases reaction rate and then confirm this relationship by analyzing data from the aluminum foil and acid experiment (confirmatory). Confirmatory activities can help reinforce challenging concepts or focus on a specific laboratory technique, such as titrating.

This process can be applied to almost any experiment using three simple strategies. First, an activity can be made into an inquiry activity if a relevant research question is developed, students are engaged in analyzing data, and students draw conclusions based on the data. Second, moving an inquiry investigation from the end of the unit to the beginning makes it a more open inquiry activity. Third, removing portions of a cookbook lab that come from a textbook, such as the procedure or data table, can also make the lab less scaffolded.

FIGURE 5

Sample rubric for assessing students' final product

Type of product:

___ poster ___ PowerPoint ___ lab report ___ other

All products must include the following:

	Full Credit	Partial Credit	No Credit
Experimental Details	Includes: 1. independent variable (IV) 2. dependent variable (DV) 3. control 4. hypothesis	One or two of the details are missing	Experimental details are not addressed in the report
Data	The data are presented in a clear, concise manner (data table, graph, or other visual representation) and properly labeled	Labels are missing, the data is unclear, or the best representation for the data is not used	The results are missing from the report or not legible.
Results	A conclusion paragraph about the relationship of the data is written and based upon evidence from the experiment. The hypothesis is also addressed.	A conclusion is made, but no evidence is used to support the conclusion or the conclusion does not address the hypothesis.	The conclusion contradicts the data or is absent from the report.
Explanation	A viable process underlying the observed phenomenon is explained (written or graphical representations with labels are acceptable) and supported by evidence from the data.	The explanation is incomplete. It does not address the main relationship described in the results or does not use data to support the explanation.	The explanation contradicts the observations or is absent from the report.
Evaluation	The overall inquiry activity is evaluated through the following questions: 1. How reliable are the data? (number of trials, human error) 2. How might you change the experiment in the future? 3. What further scientific questions arise from this activity? How might you go about finding answers to these questions?	One of the three questions is not addressed or answers to each question are incomplete.	One sentence or less is given for each question or the evaluation is absent from the report.

FIGURE 6

Schedule for open inquiry activity with aligned assessments.

Day	Agenda	Assessment
One	demonstration, four-question strategy, experimental design	Formative: experimental design diagram (check for correct trials, not multiple independent variables)
Two	develop procedure and data tables, start experiment	Formative: procedures (check for details), data tables (check for organization)
Three	complete experiment, analyze data, present results	Authentic: ability to complete performance-based tasks in lab Alternative: final lab report, presentation (check for organization, logical conclusions, use of data to justify results)

Note: Sample rubric in Figure 5 is based on the alternative assessment.

Conclusion

This article presented a content-specific example of how to practically implement an open inquiry activity in the chemistry classroom. In practice, we have been pleased with how well students develop their own experiment using the four-question strategy and experimental design diagram. We also explained how to modify the investigation into other levels of inquiry to meet instructional and student needs. Making small changes to cookbook labs can lead to big rewards. Students are more engaged and take ownership of the activity as well as the content. By using the simple strategies for scaffolding inquiry, teachers can incorporate inquiry into their chemistry instruction throughout the year and with investigations they are already using.

Lindsay Wheeler (lsb4u@virginia.edu) is a doctoral student at the University of Virginia in Charlottesville, and Randy Bell (rlb6f@virginia.edu) is a professor of science education at Oregon State University in Corvallis.

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